1) Define a Robot:

a robot is a mechanical device with Links and joints, guided by sensors, driven by actuators and Controlled through a programmed software, to handle and manipulate parts, materials, tools and devices For performing various tasks in variety of work environments.

2) Automation and Robotics:

- For the operation and Control of production or manufacture the mechanical, electrical, electronics and Computer based systems are integrate to form technology Called Automation.

3) Compare between Hard Automation and Soft Automatio

| Features | Hard Automation | Soft Automation |
|---|---|---|
| 1) Cost effective | - good at very high production volume (كميات كبيرة) | - good For moderator production volume. (كميات متوسطة) |
| 2) Flexibility | - Limited | - High |
| 3) Life Cycle | - For Long Period | - For short and medium period. |
| 4) Batch production | - Not suitable | - High suitable |
| 5) Control through SW. | - Not possible | - Easily possible. |
| 6) Efficiency of the operation. | - Comparably High (Soft متوسطة) | - Equally High. |
| 7) obsolescence of machine. (منظمة الآلة لا تتغير تماما) | - Happens with change in model. | - Doesn't happen because the software Can be changes. |

| | | |
|---|---|---|
| - Examples | - Automatic machine<br>- special Purpose machine.<br>- Transfer Lines.<br>- machine not Controlled through SW | - CNC machines.<br>- Robots<br>- Programmable machines. |

1) Robot Advantages:

[1] Environment Safty:
الروبوت يعمل في بيئات عمل خطيرة دون التأثر بشكل:
Air Polution, noise Polution, Light variation
والتي لا تناسب الإنسان للعمل فيها.

[2] Productivity parameter: (الإنتاجية):
الوقت اللازم لإنتاج المنتجات وإجراء العمليات بواسطة نظام الـ Robot أسرع من الإنسان وبالتالي تزداد الإنتاجية.

[3] Unit Cost in the Long run and Batch:
نظام الـ Robot لإنتاج أجزاء في صورة batches وليس انتاج نفس المنتج لفترة طويلة.

[4] Accuracy, repeatability and work quality of new: نظام الـ Robot في العمليات التي تحتاج دقة وتكرار بشكل دائم حيث ينتج جودة عالية.

[5] Simulation multiphlicity - it can work with multiple stimulli
(manipulators are capable of performing tasks of may stimulli at given instances)

[6] Advanced technologies can be associated with Robot such as sensors and cameras.
يمكن دمج التقنيات التي تجعل الـ Robot يحاكي الإنسان مثل الـ sensors والـ vision Camera.

-5) Robot dis Advantages:

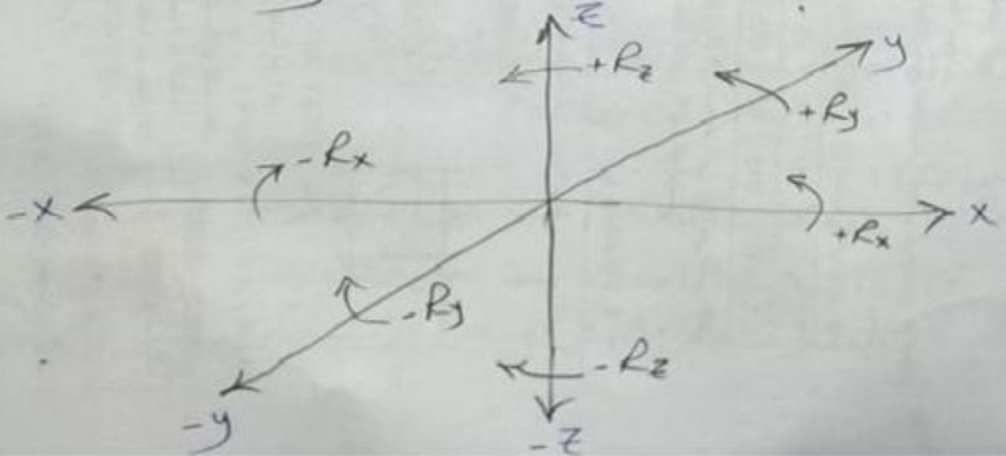
[1] Cost Constraint in investment:
تكلفة شراء، Robot وتدريبه وتشغيله وصيانته هي التي تحدد قرار شراء الـ Robot.

[2] Decision Intellgience:
الـ Robot لا يستطيع أن يفكر بذكاء مثل الإنسان وأن يـ situation ـي handle جديد هو فقط ينفذ ما تم برمجته.

[3] Replacement of Labour in a Populated Place
استبدال العامل البشري بالـ robot يؤدي إلى البطالة unemployment وخصوصاً في البلاد ذات التعداد السكاني الكبير.

[4] Real time response (سرعة استجابة بطيئة)

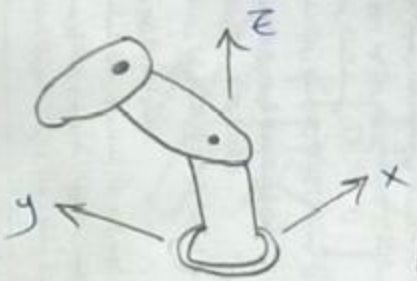
-6) Degree of freedom: (Dof): (حالات حركة الـ robot)
A body suspended in space can have:
- six positive degree of freedom:
  - 3 transLatory or Linear movement along +ve axis (على المحاور)
  - 3 rotatory anticlockwise movements. (حركة دورانية عكس المحاور)
- six negative degree of freedom:
  - 3 translatory or Linear movement along -ve axis.
  - 3 rotatory clockwise movements.



7) - The Reference Frames:

يوجد ثلاث أنواع من الـ Frames بكامة بحركة الـ Robot :

1 Base Reference Frames:



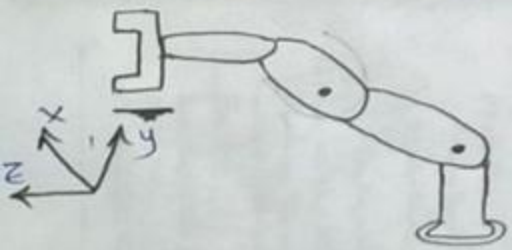

لو فرضنا إن الـ axis للقاعدة هم الـ x و y و z . نيابي هذا النوع يكون به القاعدة (Base) إما ثابتة (Fixed) أو دورانية (rotated) تدور حول x-axis حسب الـ Application .

Base → القاعدة هي بتحركة .

2 Joint Reference Frame:

- الـ Reference axis موجودة عند الـ joints والـ joint هيكون اذا بيعمل حركة دورانية (Rotational) أو حركة خطية (Translatory) or (Linear) .

3 Tool Reference Frame:




- الـ Reference axis موجودة عند الـ arm tip الـ Robot hand .

8) - Robot Joints:

- هذه الـ joints مصنوعة بعمل حركة طولية (Linear) أو دورانية (Rotary) أو كروية (Spherical) .

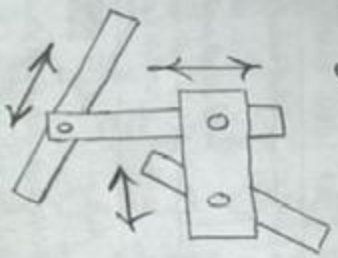
- بالصور :

1. Prismatic joints ← بعمل حركة طولية (Linear) .
2. revolute joints ← بعمل حركة دورانية (Rotary) .
3. Spherical joints ← بعمل أكثر من حركة دورانية (كروية) .

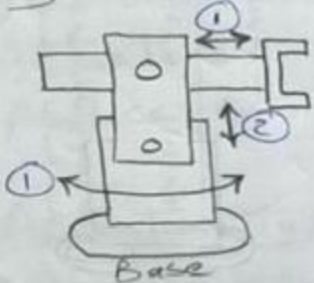
9) Robot Configurations:
انواع الحركات التي يقوم بها الـ robot.

1 Cartesian Robot: (3P):

يتكون من 3 prismatic joints والتي تعطي 3 حركات خطية (Linear) في الاتجاهات x, y, z.

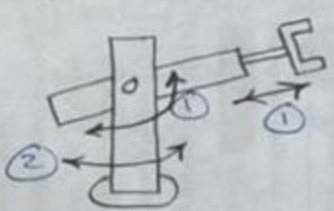


2 Cylindrical (2PR) Robot:



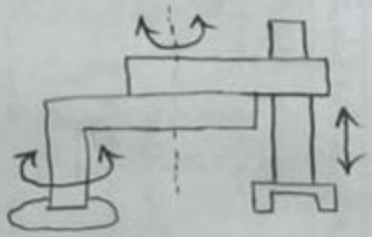

- يتكون من 2 prismatic joints والتي تعطي حركتين خطيتين (Linear) على z-axis.
- يتكون من 1 revolute joint والتي تعطي حركة دورانية (Rotary).

3 Spherical (2RP) Robot:




- يتكون من 1 prismatic joint.
- يتكون من 2 Revolute joints.

4 SCARA (Selective Compliance Assembly Robot Arm):



- يتكون من 2 horizontal parallel Revolute joints.
- يتكون من 1 vertical prismatic joint.

⇒ We can say:
(P) → Prismatic → Linear motion.
(R) → Revolution → Rotary motion.

10) Robot Components:

[1] Arms:

- ARM = Robot = Link + joint
- also Called Manipulator.
- Manipulators are the mechanical parts of a robot.

[2] End-effectors:

- also Called Gripper, Tool or Hand.
- A part Connected to the end of the arm making the robot hand.

[3] Actuators:

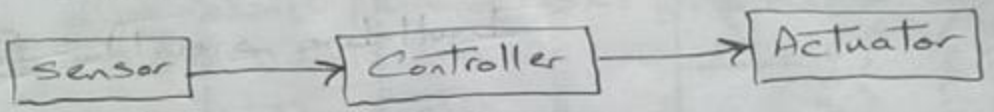
- Produce rotary, translatory movement in Links.
  يعطي الحركة الدورانية والخطية للـ Joints.
- Actuators types:
  1) hydraulic. 2) Pneumatic. 3) servo motors.
  4) stepper motors.

[4] Sensors:

- recognise the robots position while in movement or static.
- the future movements or actions depend on the Feedback of the information Collected by the sensors.
- Collect information about the surrounding environment which aids in Processing the task.
- Examples: Force sensors - vision system - speech processors - speed sensors.

[5] Controllers:

- These are electronic devices which manipulate the signals from the sensors to be provided to the drives to produce actions.
- The produced action may be matching or may not with the desired output.
- The deviation is Feedback in the form of an error which adjusts the reference input to an actuating signal.
- The Control elements and the feedback elements Constitute the Control system.




[6] Software and hardware:

- A Computer sw and Hw process through Computation of the symbolic Codes to derive the needed purpose of position, speed and accuracy of motion obtained by the kinematic equations.

11) Impact of Robotics on Direct Labour:

- A robot perform multiple tasks, Can be a substitution for more than one human workers, Leading to the displacement.
- The set up of the workspace and operating the Robots need the education and training the direct Labour in Conversion to indirect Labour.
- The new workers appointed in a robot installed industries need to be knowledged in installing, programming, inspecting, trouble shooting and maintenance of the industrial robots

- the job opportunities (devices) open up in the robot manufacturing industries for the upgraded technical human skills.

- To counter the unrest among the workers, the labour unions have to be taken into confidence through sufficient prior notice, min - careful-displacement, new technology adaption, training and guidance.

12) Need For Robots:

* Accuracy aspect:
  the robots perform tasks with highest accuracy, good quality.
* Environmental aspect:
  operates under the environments hazardous.
* Human aspect:
  human error is eliminated by use of Robot.
* skill aspect:
  robot can execute the tasks with bette skill than human.
* performance aspect:
  productivity is enhanced; produce better performance and efficiey than human.
* Automation aspect:
  the highest technology of automation in robots can give a competitive edge in the international level.

* Each Joint Can move either Revolute or Prismatic
* we Can transform Revolute movement into Prismatic.

1) Robot Configurations:

[1] Cartesian Robot: (3P):
- No. of prismatic Joints is three (x, y, z)
- Example: IBM's
- Rectangular workspace.

[2] Cylindrical Robot: (R2P):
- No. of prismatic Joints is two. (↔, ↕)
- No. of Revolute Joints is one. (↻)
- Example: GMF's
- Cylinder shape workspace.

[3] polar (spherical) Robot: (2RP):
- No. of Prismatic Joints is one.
- No. of Revolute Joints is two.
- Example: Unimate 2000. - spherical shape workspace

[4] Jointed Arm (Articulated) Robot: (3R):
- No. of Revolute Joints is three.
- Example: CinCinnati
- Irregular workspace.

⇒ Look at shapes of each one in page 19).

2) Robotic System:

The various systems that constitue a robotic system can be categorized as follows:

- Manipulator system.
- Drive system.
- Control system.
- End effectors.
- sensors.
- Vision system.
- Computer SW & HW.

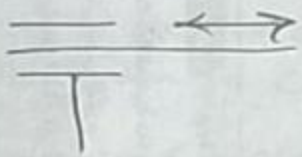
3) Joints in Robots:

| Joints | Motions | Degree of freedom |
|---|---|---|
| • Revolute Joint | rotary motion | one |
| • Prismatic Joint | sliding motion | one |
| • Cylindrical Joint | one sliding and one rotary motions | two |
| • Planar Joint | two sliding and one rotary motions | three |
| • screw pair | one translatory and one rotary motions. | two |
| • spherical Joints | three rotary motions | three |

→ Look at shapes of each one in page 20).

3) Joint symbols:

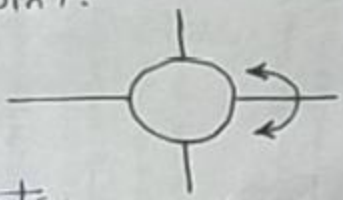
[1] Prismatic Joint:



[2] Axial revolute joint:

[3] Normal revolute joint:

[4] Back and Forth rotatio joint:



4) Functional Diagrams of Robots:

1) PUMA Robot.
2) TR3-786 Robot.
3) Kawasaki Unimate.
4) IBM-7565 Robotic systen.
5) SCARA-Type Robot.

→ Look at shapes of each one in page 21).

5) Design of GRIPPER FINGERS:

- Mechanical types -

- Fixed pivot
- Hinged pivot

1) Flat type
2) V-block type
3) Circular arc type

→ Look at page 31).

## - Non-Mechanical Types -

1) Vacuum Cup type:
   - object have to be smooth and clean.
   - Cups are made of elastic materials.
   - Vacuum is created between cup and the object

2) Adhesive Gripper:
   - handle Fabrics and Light weight materials.
   - Adhesive ribbon is alternative.

3) Magnetic Gripper:
   - Fast pickup time.
   - Variety of part sizes Can be handled.
   - Metal parts with holes Can be easily handled.
   - Requires only one surface for gripping.

4) Expandable Bladder Type:
   - Bladder made of elastic materials.
   - used to handle Fragile parts.

6) GRIPPER (end effector) mechanisms:

[1] Linkage Actuation:
   - Many design possibility using Linkage.
   - Higher gripping Force at Less actuating Force.
   - opening width and the speed of gripping depends on Linkage Configuration.

[2] Rack-pinion Actuation:

- A rack actuated by a hydraulic / pneumatic cylinder.
- pinions oscillate to move the racks.
- The fingers attached to the racks (two) open and close to grab and release the object.

[3] Cam Actuation:

- A Cam attached to a cylinder moves to and fro
- spring Loaded Followers moves on the Cam profile.
- The fingers attached to the pivoted Liver Connected to the followers open and close to release and grab the object.

[4] screw Actuation:

- The screw is rotated by a motor through reductio box.
- A threaded block engages with a screw moves Forward and backward.
- The fingers attached to levers Connected to the threaded block by a hinged joint, open and close to release and grab the object.

→ Look at Page 31).

* Robot Manipulators:
- Manipulator = Arm = joints + Links.
- A robot manipulator is Composed of a set of Links Connected together by joints.
- A robot manipulator with n joints will have n+1 Links as each joint Connects two Links.

* Mechanical Manipulator:
- modeled as an open chain of articulation.
- has many Links that are Connected by P or R joints driven by actuator.
- the open chain has to have two free ends with the starting end being Connected to the Robot base, Wher the other end represent the end effector (tool) to gap and position the object or to Carry out the operation.

* Manipulation:
- the study of the relative motion giving the relationship between the objects themselves or the object and the manipulator elements.
هي دراسة الحركة النسبية والتي تعطي العلاقة بين الـ objects وبعضها أو بين الـ objects والـ manipulator elements.

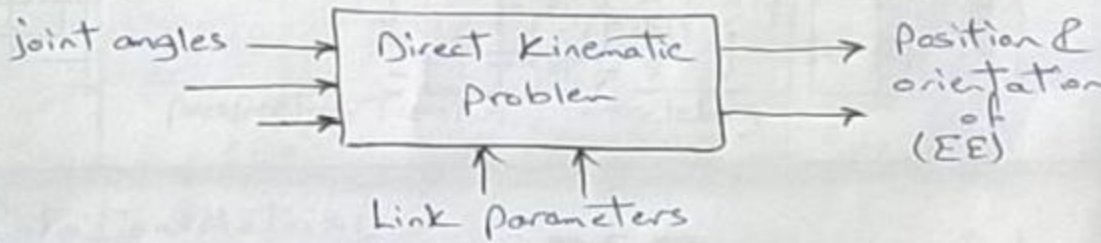
* Robot Arm Kinematics:
- Description of motion of the robot without Consideration of the forces and torques Causing the motion. (Kinematics is a geometric description)
- the motion is described as a function of time.
وصف تحليلي للحركة الهندسية للـ manipulator بالنسبة لنظام الإحداثيات للـ base frame.

# Kinematics

Forward kinematics — Inverse kinematics

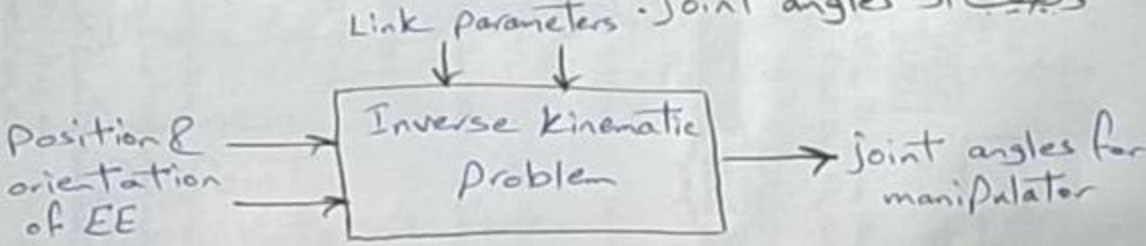
* Forward kinematics: (Direct):
- Determination of the (actual) position and orientation of the end-effector.
- given the values for the joint variables.
- required to give Feedback about end-effector pose.

- بيعتمد على قيم ابتدائية لل joint angles و Link parameters
- بطلع ال position و orientation لل end-effector (EE)




* Inverse kinematics:
- Determination of the values of the joint variables
- given the (desired) position and orientation of the end-effector.
- required to determine the control action.

- بيعتمد على ال position و orientation لل (EE) و Link parameters
- بطلع ال joint angles



* Transformations:
- the relation between the body attached Frame with the base frame of reference.
- transformation is represented by the following Component transformations:
1) Rotation Matrix.
2) Translation or Position vector.
3) prespective transformation.
4) scaling or stretching.
- The transformation Matrix is 4x4 Matrix consist of:

| | |
|---|---|
| Rotation Matrix (3x3) | Position vector (3x1) |
| prespective Transfor.. (1x3) | stretching (1x1) |

* Rotation Matrix:
- position vector:
- representing a point in three dimensions.
- operated by Rotation matrix to map its co-ordinates in the rotated or body attached reference frame with the base reference frame.
- حيث نقطة بالنسبة الإحداثيات ثلاثية, وعند على دوران حول نقطة محاور ثابت بإمكان الجديد للنقطة بالنسبة لل base frame يكون عندي Rotation Matrix.

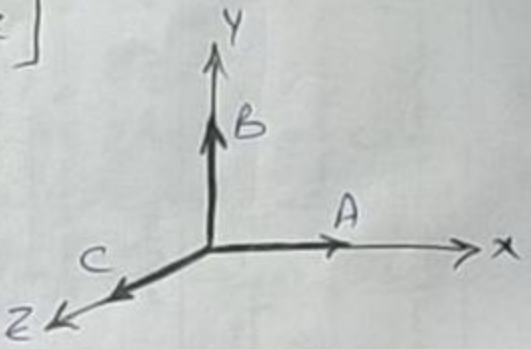
# Assume:
P: Point
o ABC: rotated Frame
o xyz: base frame

$$P_{ABC} = (P_a, P_b, P_c)^T = \begin{bmatrix} P_a \\ P_b \\ P_c \end{bmatrix} = P_a c_a + P_b c_b + P_c c_c$$

$$P_{XYZ} = (P_x, P_y, P_z)^T = \begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = P_x c_x + P_y c_y + P_z c_z$$

$$\boxed{P_{XYZ} = R\, P_{ABC}}$$

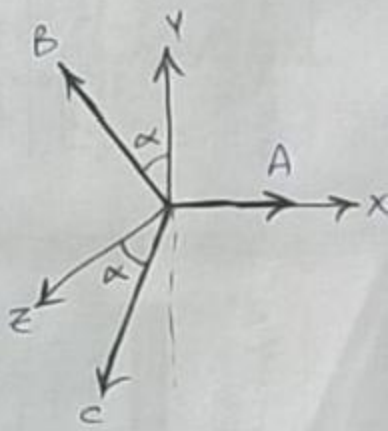
$$\boxed{P_{ABC} = R^{-1} P_{XYZ}}$$




- Rotation about x-axis:

$$P_{XYZ} = R(x, \alpha)\, P_{ABC}$$

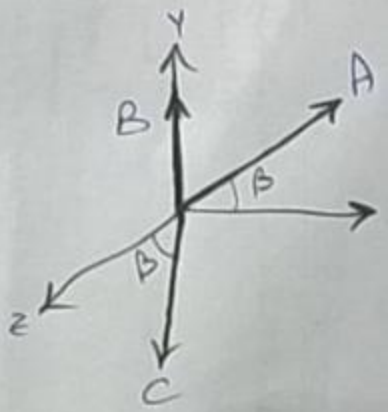
$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} P_A \\ P_B \\ P_C \end{bmatrix}$$




- Rotation about y-axis:

$$P_{XYZ} = R(y, B)\, P_{ABC}$$

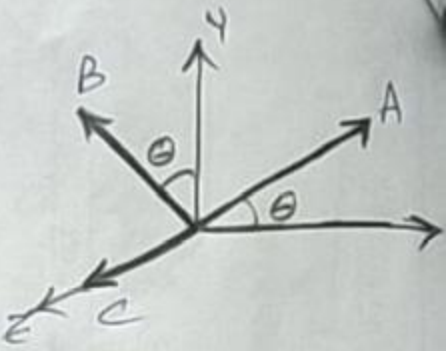
$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} \cos B & 0 & \sin B \\ 0 & 1 & 0 \\ -\sin B & 0 & \cos B \end{bmatrix} \begin{bmatrix} P_A \\ P_B \\ P_C \end{bmatrix}$$



- Rotation about Z-axis:

$$P_{XYZ} = R(Z,\theta)\, P_{ABC}$$

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} P_A \\ P_B \\ P_C \end{bmatrix}$$




- الدوران مع عقارب الساعة (↻) تكون الزاوية سالبة ($-\alpha$)
- الدوران عكس عقارب الساعة (↺) تكون الزاوية موجبة ($+\alpha$)
- لو مفيش دوران حقيقي ← Rotation Matrix = I (المصفوفة الوحدة)

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$\cos\theta = \cos 0 = 1$
$\sin\theta = \sin 0 = 0$
} No Rotation

- $ABC \neq BCA \neq CBA$

ترتيب الضرب × المصفوفة يفرق.

- $R(x,30^\circ)\, R(y,60^\circ) \neq R(y,60^\circ)\, R(x,30^\circ)$

ترتيب الحركة مهم ويفرق معايا.

* Inverse Transformation:

- Rotation Matrix:
- If two Coordinate frames are orthonormal (متعامدة) then:

$$x = RA$$
$$A = R^{-1}x = R^T x \qquad (T: \text{Transpose})$$

| Rotation | R Matrix | $R^{-1} = R^T$ |
|---|---|---|
| 1) $R(x,\alpha)$ | $\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$ | $\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix}$ |
| 2) $R(y,\beta)$ | $\begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$ | $\begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$ |
| 3) $R(z,\theta)$ | $\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$ | $\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$ |

* Composite Rotation Matrix:

- The multiplication of matrices is not Commutative
- a sequence of rotation can be represet as:
  1) Rotation of OABC by angle $\beta$ about OY-axis.
  2) Rotation of ~ ~ ~ $\theta$ about OC-axis.
  3) Rotation of ~ ~ ~ $\alpha$ ~ OA-axis

$$R = R(y,\beta) \cdot I_3 \cdot R(C,\theta) \cdot R(A,\alpha)$$

$$\left[ \begin{matrix} \text{Pre-multiply} \\ (XYZ) \end{matrix} \cdot I_3 \cdot \begin{matrix} \text{Post-multiply} \\ (ABC) \end{matrix} \right]$$

- Examples From page 46) to page 51).

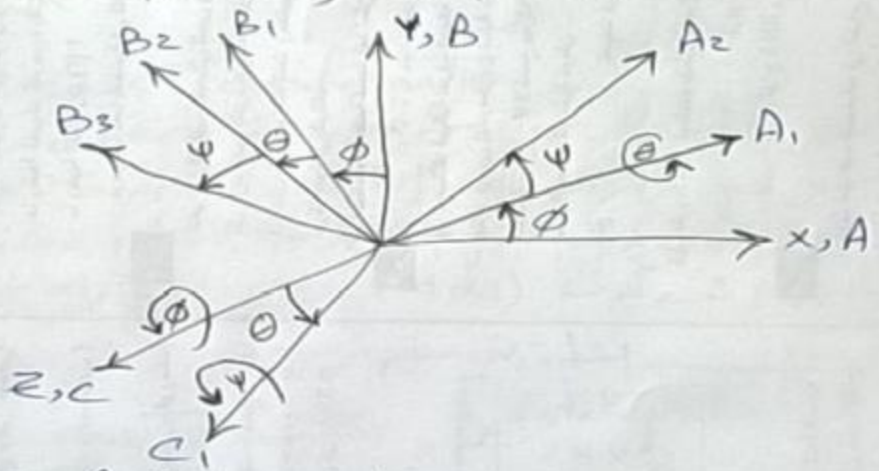
* Euler angle Representation:

- System I of Euler angles:

$$R(\phi,\theta,\psi)_I = R(z,\phi)\; R(A,\theta)\; R(C,\psi)$$

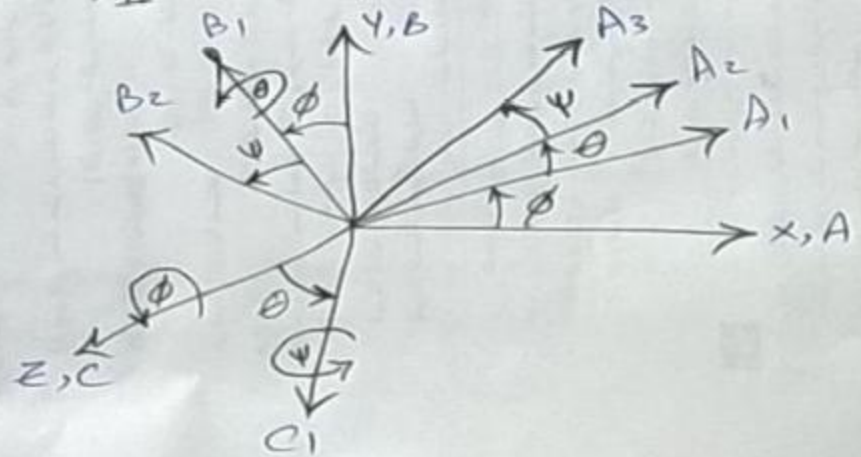
$$= \begin{bmatrix} c\phi & -s\phi & 0 \\ s\phi & c\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\theta & -s\theta \\ 0 & s\theta & c\theta \end{bmatrix} \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Where: $c \rightarrow \cos$ , $s \rightarrow \sin$



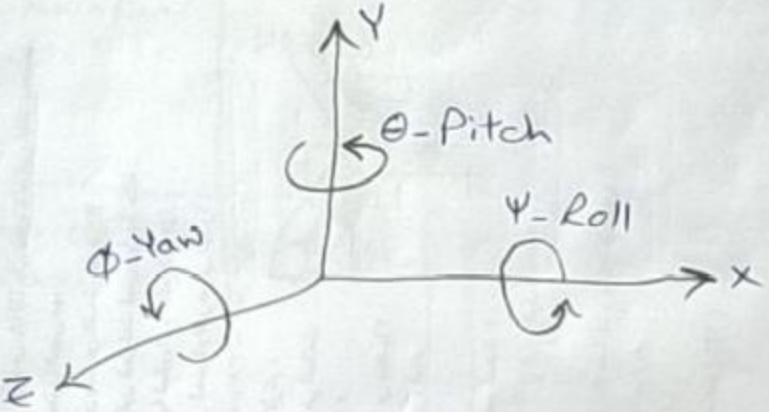

- System II of Euler angles:

$$R(\phi,\theta,\psi)_{II} = R(z,\phi)\; R(B,\theta)\; R(C,\psi)$$



- Roll - Pitch - Yaw System of Euler Angle:

$$R(\phi,\theta,\psi) = R(Z,\phi)\, R(Y,\theta)\, R(X,\psi)$$




* Homogeneous Transformation:

- إذا تم سؤالي سابقاً لاتضمن حركة Linear إلى Rotation Matrix
هي نقطة تعبر عن حركة الـ Rotational ولاتضمن الحركة الـ Linear
بدل (P) للنقطة Position vector الاعتبار يجب انه يكون الـ
سم (3×1) انه يكون (4×1) ويصبح لشكل العام لـ Matrix

كما يلي: ← النقطة التي سيتم تحويلها

$$\text{Homogeneous Transformation Matrix} = \begin{bmatrix} \text{Rotation Matrix } (3\times3) & \text{Position vector } (3\times1) \\ \text{Prespective Transformation } (1\times3) & \text{scale Factor } (1\times1) \end{bmatrix}$$

(وصف الحركتين الطولية والدورانية)

← دائماً = 0 ← = 1

$$P_{XYZ} = H\, P_{abc}$$

Fixed based Frame ← Mobile Frame

- the homogeneous Transformation maps the points in (OABC) Frame with the reference frame (OXYZ).
- الـ Frame الذي ينسب اليه هو الذي بدأ منه الحركة.

| | | |
|---|---|---|
| Homogenous Rotation about x-axis | $H(x,\alpha)$ | $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c\alpha & -s\alpha & 0 \\ 0 & s\alpha & c\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ |
| Homogeneous Rotation about Y-axis | $H(Y,\phi)$ | $\begin{bmatrix} c\phi & 0 & s\phi & 0 \\ 0 & 1 & 0 & 0 \\ -s\phi & 0 & c\phi & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix}$ |
| Homogeneous Rotation about Z-axis | $H(Z,\theta)$ | $\begin{bmatrix} c\theta & -s\theta & 0 & 0 \\ s\theta & c\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ |
| Homogeneous Translation by a vector $P_{xyz}$ | $H_{trans}(\ )$ | $\begin{bmatrix} 1 & 0 & 0 & P_x \\ 0 & 1 & 0 & P_y \\ 0 & 0 & 1 & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$ |

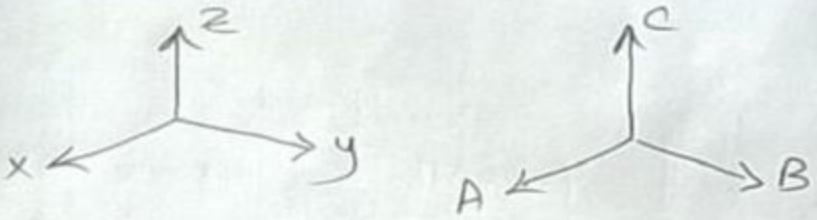
- geometric interpretation of homogenous Transformation

$$P_{xyz} = H \cdot P_{abc}$$

$$P_{abc} = H^{-1} \cdot P_{xyz}$$

($H^{-1}$ represent the orientation of the Reference Frame with respect to rotated mobile Frame)

- Inverse homogeneous Transformation:




$$P_{xyz} = H \cdot P_{abc}$$

$$P_{abc} = H^{-1} \cdot P_{xyz}$$

How Can we get $H^{-1}$:

$$H = \left[\begin{array}{ccc|c} R_{(3\times3)} & & & P_{(3\times1)} \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

R: Rotation
P: translation.

$$H^{-1} = \left[\begin{array}{ccc|c} R^T_{(3\times3)} & & & -R^T P \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

If we have $H(z,\theta) = \begin{bmatrix} C\theta & -S\theta & 0 & P_x \\ S\theta & C\theta & 0 & P_y \\ 0 & 0 & 1 & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$

then;

$$H^{-1}(z,\theta) = \begin{bmatrix} C\theta & S\theta & 0 & -(P_x C\theta + P_y S\theta) \\ -S\theta & C\theta & 0 & -(-P_x S\theta + P_y C\theta) \\ 0 & 0 & 1 & -P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Examples From Page 59) to Page 71)